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TESTS WITH A PORTABLE WIND TUNNEL FOR DETERMINING WIND EROSION THRESHOLD VELOCITIES

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Abstract – A portable open-floored wind tunnel was used to develop threshold wind speeds over two pebble covered desert soils and a sandy agricultural soil.

I. INTRODUCTION

The fluid threshold velocity for soil movement may be defined as the velocity at which aerodynamic forces are sufficient to dislodge particles from the soil and initiate movement; this velocity is dependent on both the aerodynamic forces and the forces holding the particle in the soil. Theoretical studies have been based on simple soil systems and idealized particles. The soil systems considered by theoretical treatments have been idealized systems of single particles on planar surfaces (Punjrath and Heldman, 1972), and spherical particles in monodisperse particle beds (Iversen *et al.*, 1973; Ishihara and Iwagaki, 1952; Iversen *et al.*, 1976). Experimental studies of threshold velocities for simple soil systems consisting of loose monodisperse and unmixed particles are reported by Bagnold (1941), Ishihara and Iwagaki (1952), Chepil (1951), and Greeley *et al.* (1973). Marshall (1971) and Lyles and Allison (1976) have made studies in which increase of threshold velocity due to momentum stress partitioning by nonerodible roughness was considered.

Although idealized soils consisting of loose, monodisperse particles have been studied for threshold velocities and the effect of nonerodible elements has been studied separately, very little data exists on the threshold velocities for natural soils which have effects of nonerodible elements as well as soil coherence. Such data and complementary data on physical conditions of the surface material, coupled with existing empirical and theoretical work on threshold velocities, could be used to direct new lines of inquiry in the study of threshold velocities of erosion and could provide valuable information for land managers concerned with wind erosion potential. Clements *et al.* (1963) describe a set of observations of threshold velocities generated by a blower over natural desert surfaces. Threshold values are reported in single-point values without aerodynamic roughness heights, however. Also, there is no mention of attempts to simulate the surface turbulent boundary layer with the blower arrangement used. In this paper, I will describe tests of a portable wind tunnel designed to simulate the turbulent boundary layer over natural soil surfaces. In these tests, wind speeds were increased until erosion was initiated and these speeds were recorded as threshold erosion wind speeds. The test soils were in differing states of aggregation and had differing amounts of small-scale (smaller than 3 cm dia.) non-erodible elements present on their surfaces.

II. EXPERIMENTAL

Wind tunnel design

A portable wind tunnel was built with an open-floored test section so that a variable-speed turbulent boundary layer could be formed over a flat soil containing small-scale roughness elements. The wind tunnel used a two-dimensional, 5 : 1 contraction section with a honeycomb flow straightener and a roughly conical diffuser attached to the working section in a configuration similar to that described by Wooding (1968). Dimensions of the cross section of the working section are 15.24 × 15.24 cm and the length of the working section is 300.5 cm. A photograph of the wind tunnel is shown in Fig. 1.

Velocity profiles and cross sections are shown in Fig. 2 for the wind tunnel working section at a point 1 cm from the contraction section, at the middle of the working section and at the end of the working section near the diffuser. The mean velocity profiles and cross sections show an orderly progression from a uniform velocity delivered at the exit of the contraction section to a turbulent boundary layer for all walls, with the thickest layer over the ground at the exit of the working section. The plots show a thickening of the boundary layer with distance, an increase of center velocity compensating the increased frictional slowing of the air near the boundaries. The intercept for zero velocity on the height scale (z_0) is consistent for the rough bottom surface and the smoother wall for both the middle and end positions. The value of this roughness height (z_0) is larger for the rough floor surface compared to the smooth wall surface, as would be expected. Smoke candle tests showed streamlines to be smooth within the tunnel with vertical smoke diffusion from the floor upwards. Atmospheric turbulence differs with that generated by the wind tunnel in the thickness of the boundary layer and the consequent scales of vertical motions. However,

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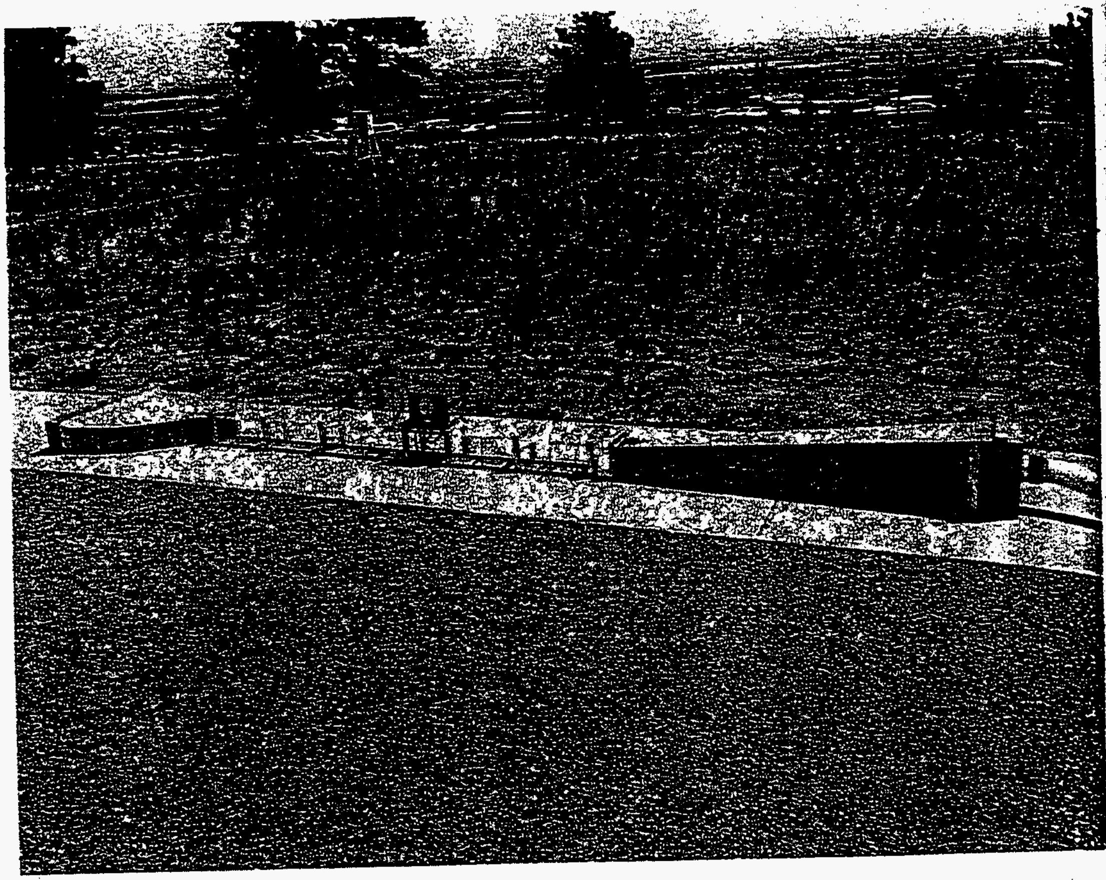


Fig. 1. The NCAR portable wind tunnel.

since we are considering only the surface interactions of wind and soil, the scale of motions of natural atmosphere and wind tunnel atmosphere very near the surface are fairly similar since natural atmospheric motions near the ground are limited by height.

Wind profiles

Wind speed data were collected at several heights above the surface midway across the end of the working section. The pitot tube anemometer was calibrated using the NCAR wind tunnel anemometer calibration facility and was corrected for temperature and pressure changes. The mean velocity (u) vs height (z) data were fitted to the function for aerodynamically rough flow (see Priestley, 1959)

$$u = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right),$$

where u_* is friction velocity, z_0 is roughness characteristic of the surface height and k is Von Karman's constant using a nonlinear least squares routine. The threshold velocity profile was obtained for that profile at which continuous movement of grains was first visible. A mean wind profile for a natural desert surface which did not erode is shown in Fig. 3. Threshold velocities and aerodynamic roughness heights are reported in terms of the friction velocity and the roughness height z_0.

Location of field tests and soil conditions

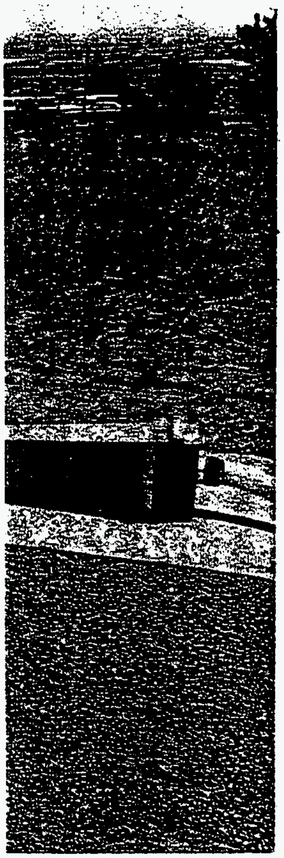
Three tests were conducted on soils near Socorro, New Mexico and near Plains, Texas. Two desert soils of varying pebble cover were chosen near Socorro, New Mexico and one farmland soil which lacked nonerodible elements but which had considerable surface coherence was chosen near Plains, Texas. As far as possible, each soil was tested in its natural condition. For the desert soils, however, the soils were also tested in a disturbed condition in which surface aggregation was broken by walking on the soil surface, since the wind velocities developed by our wind tunnel were insufficient to initiate erosion on the undisturbed surfaces. Soil subgroups and families, as well as surface textures, are given in Table 1.

Soil was collected for subsequent soil moisture determination, for size distribution analysis by dry sieving, and for modulus-of-rupture analysis (see Reeve, 1965). The dry sieving size analysis was done mainly to quantify the percentage of large nonerodible particles in the soil and the modules of rupture was determined to give a relative measure of the resistance to erosion of the coherent dry soil (see Smalley, 1970). Modulus of rupture is the maximum bearable tensile stress of a soil so that it would be expected that shear stress of the wind which exceeds this quantity would erode the soil. As is reflected in Table 2, soil 2 is protected by a pebble covering and soils 1 and 3 are relatively smooth.

In this paper I will arbitrarily classify such nonerodible elements as pebbles and soil aggregates as soil factors and such nonerodible elements as bushes and large boulders as aerodynamic factors. Thus the non-erodible elements smaller than 3 cm dia. will be considered part of the soil while larger objects will not be so considered. For the present tests large nonerodible elements (such as boulders and bushes) were avoided.

III. RESULTS AND DISCUSSION

Values of threshold friction velocity and aerodynamic roughness height are shown in Table 3. At



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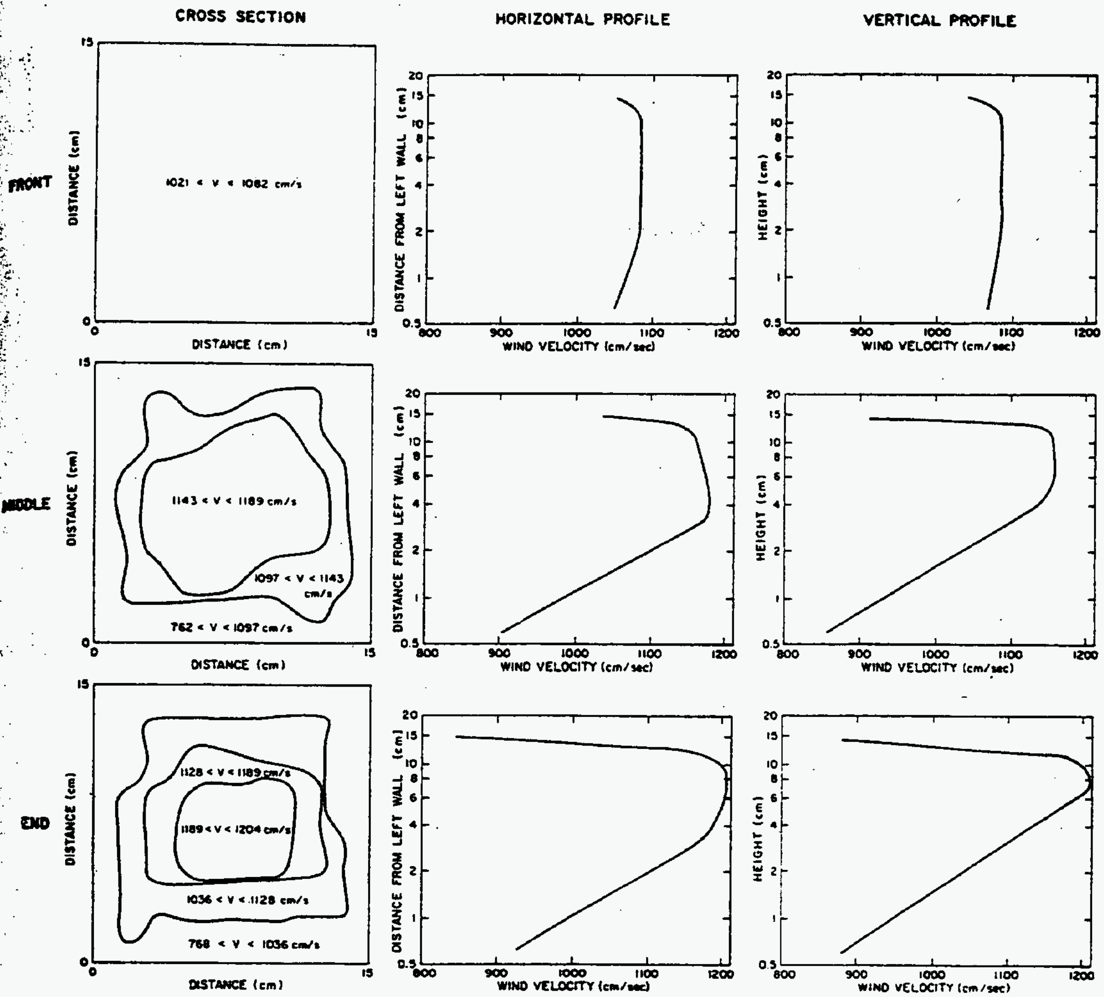

Fig. 2. Cross sections and profiles of mean wind speed for positions at the beginning, middle, and end of the test section. The top row shows cross sections of the wind speeds, the middle row shows the wind profile across the mid-height of the test section starting at the left wall, and the bottom row shows the wind profile from the floor to the ceiling taken at the mid-width of the test section.

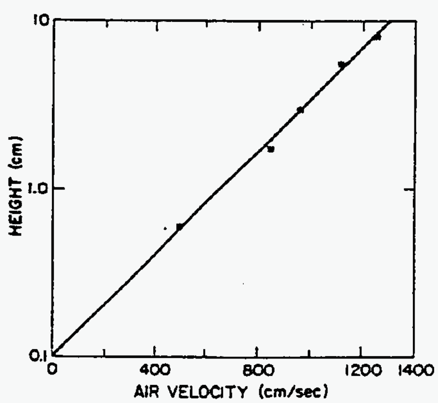

Fig. 3. A typical wind speed profile for a noneroding desert soil showing data points and the fit to those points.

would be expected, soil 2 has the largest value of aerodynamic roughness height due to the presence of pebbles on the soil surface. Indeed, Table 2 shows that more than 50% of the mass of the dry material in the sample has a diameter greater than 4 mm. These nonerodible elements protected the underlying loose (disturbed) material, as is shown by the high threshold velocity of 121.9 cm s^{-1}. The effect of the nonerodible pebbles is seen by comparing the threshold friction velocity for the same soil with a much smaller number of pebbles present (only 16.3% of soil particles compared to 53.3% larger than 4 mm for soil 2). The threshold velocity of soil 1 is 34.2 cm s^{-1} lower than that of soil 2, which must be owing to the presence of the nonerodible elements in soil 2 since both soils were disturbed by crushing before the test took place. The effect of soil size distribution is seen by comparing soil 1 and soil 3. The coarser structure of soil 1 compared to

Table 1. Soils sampled

Soil	Subgroup and family	Location	Surface texture
1	Typic ustorthent,* fine, ml, mesic	Near Socorro, NM	loam
2	Typic ustorthent, ml, mesic	Near Soccoro, NM	loam
3	Aridic Calciustoll,† fn-lmy (calcareous)	Near Plains, TX	loamy fine sand

* Classified tentatively by Dr. John Hawley, New Mexico Bureau of Mining and Mineral Resources, Socorro, New Mexico.

† From *Soil Survey* for Yoakum Company, Texas, U.S. Department of Agriculture, Soil Conservation Series 1960, No. 15, 1964.

Table 2. Size distributions (percentage of mass) of test soils determined by dry sieving (size in mm)

Soil	<0.106	0.106–0.25	0.25–0.5	0.5–1	1–2	2–4	>4
1	15.4	11.1	11.1	12.3	14.7	19.0	16.3
2	11.9	6.9	8.8	7.6	5.6	6.0	53.3
3	11.1	46.5	21.9	6.0	5.4	5.5	3.6

Table 3. Threshold velocities and moduli of rupture for test soils

Soil	u_* Thresh	Z_0 (cm)	Modulus of rupture of consolidated soil (bars)	Soil (%)
1	87.7	0.06	1.43	0.6
2	121.9	0.16	1.36	0.6
3	43.0	0.06	1.36	0.7

soil 3 is shown in the size distributions of Table 2: 57.6% of the mass of soil 3 is smaller than 0.25 mm, while only 26.5% of the mass of soil 1 is smaller than 0.25 mm. The modulus of rupture values and soil moisture values are quite similar for all three soils (1.36–1.43 bars and 0.6–0.7% respectively) and the aerodynamic roughness of soils 1 and 3 is approximately the same, 0.06 cm. Both soils were dry and unprotected by vegetation. The large percentage of particles in the size range around 100 μm, which corresponds to a minimum threshold velocity needed to initiate wind erosion (Chepil, 1951), is the main difference in the physical parameters measured in this study.

The threshold velocity has been measured for a different exposure of a Portales loam soil similar to soil 3 under natural conditions by using anemometers at several heights to determine the friction velocity (Gillette, 1974). The threshold velocity measured was about 30 cm s^{-1}, significantly lower than the velocity measured by the wind tunnel. I feel that this lower velocity corresponded to a finer dry sieving texture (94.1% of the mass smaller than 0.42 mm compared to 79.5% of the mass of soil 3 smaller than 0.5 mm). The finer texture would correlate with less of the soil material being in nonerodible aggregates which would have the effect of partitioning the momentum transfer away from the erosion process (Marshall, 1971).

CONCLUSION

A portable wind tunnel having a floor formed by a small flat expanse of natural soil may be used to create artificial turbulent winds to test for soil threshold velocity. Three soils were tested, ranging from a pebble covered desert soil to a relatively sandy agricultural soil. Threshold velocities for the three soils showed the importance of the size distribution of the surface material. The larger proportion of mass in particles or aggregates which were nonerodible rendered the material increasingly nonerodible. Thus larger threshold velocities were required to initiate wind erosion.

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